EARTH SURFACE PROCESSES AND LANDFORMS, VOL. 21, 205–216 (1996)

WIND TUNNEL EXPERIMENTS OF AEOLIAN DUST DEPOSITION ALONG RANGES OF HILLS

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Received 8 December 1993
Accepted 2 October 1994

ABSTRACT

Wind tunnel experiments of aeolian dust deposition on topographic scale models of ranges of hills were conducted. Different hill sizes and hill spacings were used, and comparisons with the deposition patterns over single, isolated hills were made. Dust profiles over ranges of hills differ from the profiles over identical, but isolated hills. On isolated hills the sedimentation maximum on the windward hillslope is always single and located on the concave part of the slope. In the case of ranges of hills, the maximum is either single or double, with the second peak on the convex part of the windward slope in the latter case. The local sedimentation maximum on the convex leeslope, which is rather unimportant on isolated hills, is much more developed in multiple-hill topography. Also, dust deposition on the leeslopes is significantly higher in multiple-hill topography than on isolated hills.

Dust patterns on ranges of hills may be affected by the dust shadow created by the most upstream-located hill. If hills succeed each other quickly, they are located within the shadow zone and are protected from important dust deposition.

The plume of high air dust concentration that is created by a hill largely determines the dust pattern on the next hill. As a result of the supply of dust from above by the descending plume, areas that are normally devoid of dust now experience significant dust deposition.

KEY WORDS aeolian dust; dust deposition; hill; topography; wind tunnel

INTRODUCTION

The dynamics of atmospheric dust (particles smaller than 63 μm, which are commonly transported in suspension) is significantly affected by terrain topography. Topography largely determines the spatial patterns of dust transport, short-term dust deposition and long-term dust accumulation (Goossens, 1988a; Goossens and Offer, 1990, 1993). If surface roughness is sufficiently uniform, it also largely determines the spatial pattern of dust erosion (Offer and Goossens, 1994). In hilly terrain, dust and dust-derived deposits are, therefore, characterized by an important spatial variation in occurrence and sediment depth (Rozycki, 1967; Bouten *et al.*, 1985; Clowes and Comfort, 1989).

Wind tunnel simulations of aeolian erosion, transport and deposition are an important aid in understanding the role of topography in aeolian geomorphic processes. Most wind tunnel studies focus on the behaviour of sand. Experimental studies of the dynamics of dust are much sparser, although aeolian dust deposits are much more widespread than aeolian sand deposits (Pye, 1987). Experiments by Goossens (1988a), Goossens and Offer (1990, 1993) and Offer and Goossens (1994) have shown that wind tunnel simulations on topographic scale models can predict the spatial patterns of aeolian dust erosion, deposition and accumulation in hilly terrain, provided careful attention is paid to similitude.

Figure 1 shows the typical dust sedimentation profile over an isolated, symmetrical hill standing perpendicular to the wind. Assuming a flat area upstream of the hill, dust deposition starts to increase once the windward slope is reached. It increases continuously up the slope until a maximum is reached close to the inflection line (where the slope changes from concave to convex). Downwind of the inflection line, dust

CCC 0197–9337/96/030205–12

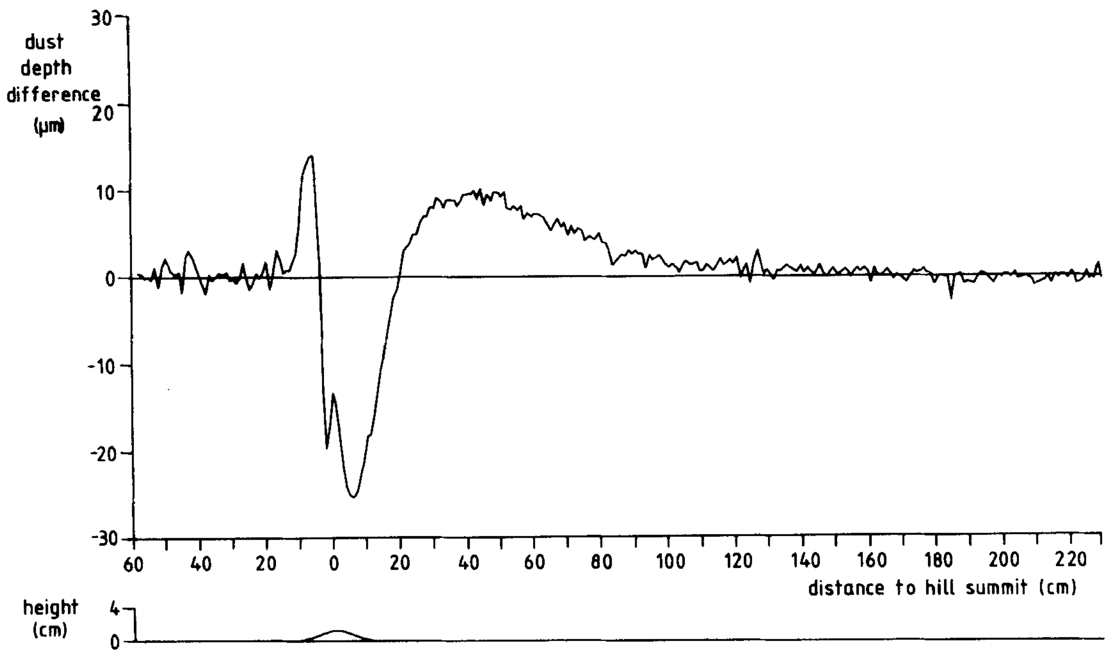


Figure 1. Typical dust deposition profile over a symmetrical hill. Abscissa values represent distance to the hill summit. Ordinate values indicate the difference in dust depth between the curved hill surface and a flat reference surface. Airflow is from left to right; the hill is 25 cm wide and 3 cm high

deposition drops dramatically. Typically, two sedimentation minima are observed: the first immediately before (or at) the summit, and the second one more downwind, on the leeslope. Both minima are separated by a zone of slightly increased sedimentation. Deposition remains very low all over the leeslope. Downstream of the hill, a second zone of increased sedimentation occurs. This zone damps out gradually until 'normal' deposition values (equal to those upstream of the hill) are again reached. From then on, sedimentation remains constant.

Several studies of dust deposition in complex topography, both in the wind tunnel (at reduced scale) and in the natural environment (at full scale), showed that the general occurrence of dust in such areas is consistent with the pattern described above, provided the landforms do not interfere too much with each other (Goossens, 1988a; Goossens and Offer, 1990). If landforms are rather large, and if they succeed each other quickly, the airflow pattern over and around a landform is significantly affected by the upstream landforms, and so is the dust pattern. For example, if two hills are located close to each other, it can be expected that the downwind hill may suffer from a dust-shadow effect created by the upwind hill, and will be almost free of dust. Similarly, a hill located in the zone of increased sedimentation downwind from a more upstream-located hill may be expected to show higher deposition values than normal. Also, the question arises as to what will happen if a complete series of hills, succeeding one another very quickly, appears in the landscape. To date, very little is known about topographic interference, particularly in relation to aeolian dust patterns.

It is the aim of this paper to study dust deposition patterns over various topographic configurations. Dust patterns are analysed for different combinations of hill size and hill spacing, and comparisons are made with the reference profiles over identical but isolated hills. The study is, of course, restricted since the total number of topographic combinations is unlimited, but the landform combinations investigated were selected such that, if topographic interference plays a significant role in dust deposition and accumulation, the effects should be recognizable in the profiles.

EXPERIMENTAL FACILITIES

All experiments were carried out in the closed-return wind tunnel of the Laboratory for Experimental Geomorphology of the Katholieke Universiteit Leuven, Belgium. Experiments were conducted in the large test channel, which is 760 cm long, 120 cm wide and 60 cm high. Dust transport was generated by means of an Engelhardt laboratory dust-cloud producer. This apparatus ensures a continuous feed to the air current of natural dust, and allows the operator to adjust dust discharge. A more detailed description of the wind tunnel and the dust-cloud producer can be found in Goossens and Offer (1988).

Topographic profiles and dust thicknesses were measured with an Optocator laser instrument with gauge probe types nos 2008 and 2301, respectively. The accuracy of the instrument is 64 μm for the 2008 gauge probe and 2 μm for the 2301 gauge probe.

Wind velocities were measured with a standard pitot tube and a digital Furness FC016 manometer with an accuracy of 0·001 mm water pressure.

EXPERIMENTAL PROCEDURE

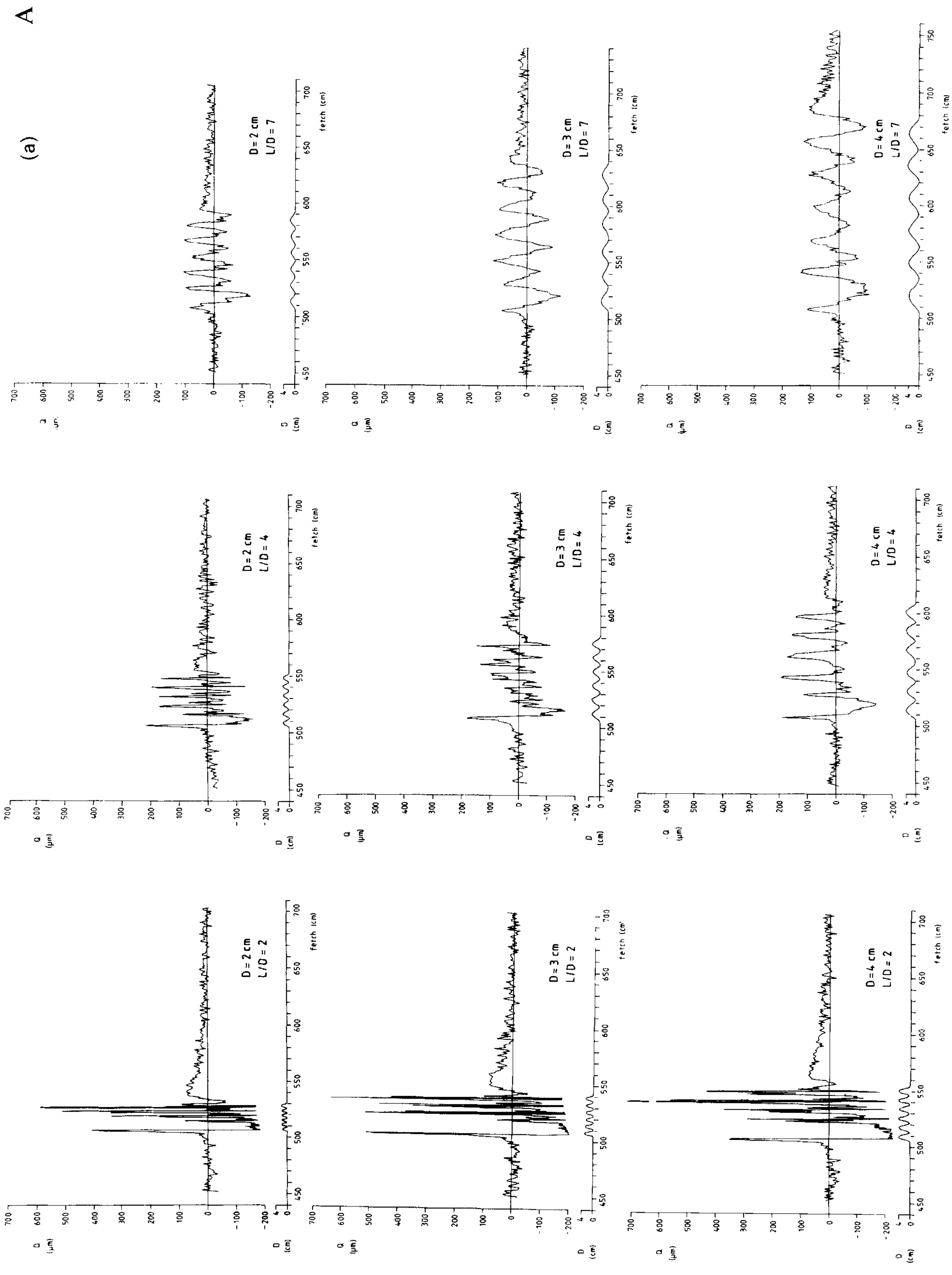
All experiments were executed with dust prepared from Belgian Brabantian loess. The loess was dried, ground and sieved through a 63 μm sieve to exclude all sand particles. In the sifting, some of the finest particles were lost in small dust clouds. The remaining sediment consisted of 95 per cent silt (2–63 μm) and 5 per cent clay (<2 μm). It had a median diameter of 29 μm, which corresponds closely to the size of dust particles that settle on the earth's surface during natural atmospheric dust storms (Yaalon and Ganor, 1979). Only 1 per cent of the particles was coarser than 50 μm.

Eighteen experiments were conducted in the wind tunnel: nine with multiple-hill substrata, and nine with single, isolated hills. Each multiple-hill substratum was composed of six identical, symmetrical hills with the length axis perpendicular to the wind. The slopes were concave–convex, and inflection lines were located about half-way along the slopes. All substrata were prepared from zinc plates 2 mm thick and 30 cm wide, which were folded in the desired shape. Three hill heights (D) were selected: $D = 2$ cm, $D = 3$ cm and $D = 4$ cm. The distance between two adjacent hilltops (L) was chosen such that the following three L/D values were obtained: $L/D = 2$, $L/D = 4$ and $L/D = 7$. The same nine combinations of D and L/D were used in the single-hill substrata.

A 450 cm fetch, consisting of a plastic substratum with gentle undulations, was installed in the wind tunnel before the experiments started. The characteristics of the boundary layer produced by this fetch were measured 505 cm from the leading edge of the wind tunnel channel. Boundary layer depth was 18·4 cm, free-stream air velocity was 192 cm s^{-1} and friction velocity was 9·3 cm s^{-1}. Expressing the velocity profile as a power function, the power exponent was equal to 0·15, which corresponds to a typical neutral-stability velocity profile over a hilly region with no large surface roughness elements (Counihan, 1975). The ratio of terminal fall velocity (of the dust particles) to the friction velocity was equal to 0·7. According to the criteria proposed by Tsoar and Pye (1987), dust transport during the experiments thus occurred in true suspension. Field validations of former wind tunnel experiments of aeolian dust deposition on topographic scale models have shown that the aerodynamic conditions adopted for the dust experiments described in this paper allow a direct extrapolation of the wind tunnel results to natural (full-scale) situations (see, for example, Goossens and Offer, 1990, 1993).

Before each experiment, the experimental substratum was put in the wind tunnel in such a way that the first (most upwind) hill started at a fetch of 505 cm. The 30 cm wide zinc plate was placed in the centre of the tunnel. Two supplementary plates 30 cm wide, each showing exactly the same substratum, were placed on both sides of the test plate to eliminate fringe disturbances. The remaining space between the supplementary plates and the wind tunnel walls was covered by a folded sheet of paper, showing the same undulation(s) as the test surface.

Figure 2. Compilation of the 18 dust profiles measured. The position of the hills is indicated below each curve. See text for aerodynamic conditions; airflow is from left to right. Q = dust depth difference between the curved hill surface and a flat reference surface. (A) Six-hill profiles; (B) one-hill profiles


A
(a)
D = 2 cm
L/D = 7
D = 3 cm
L/D = 7
D = 4 cm
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D = 2 cm
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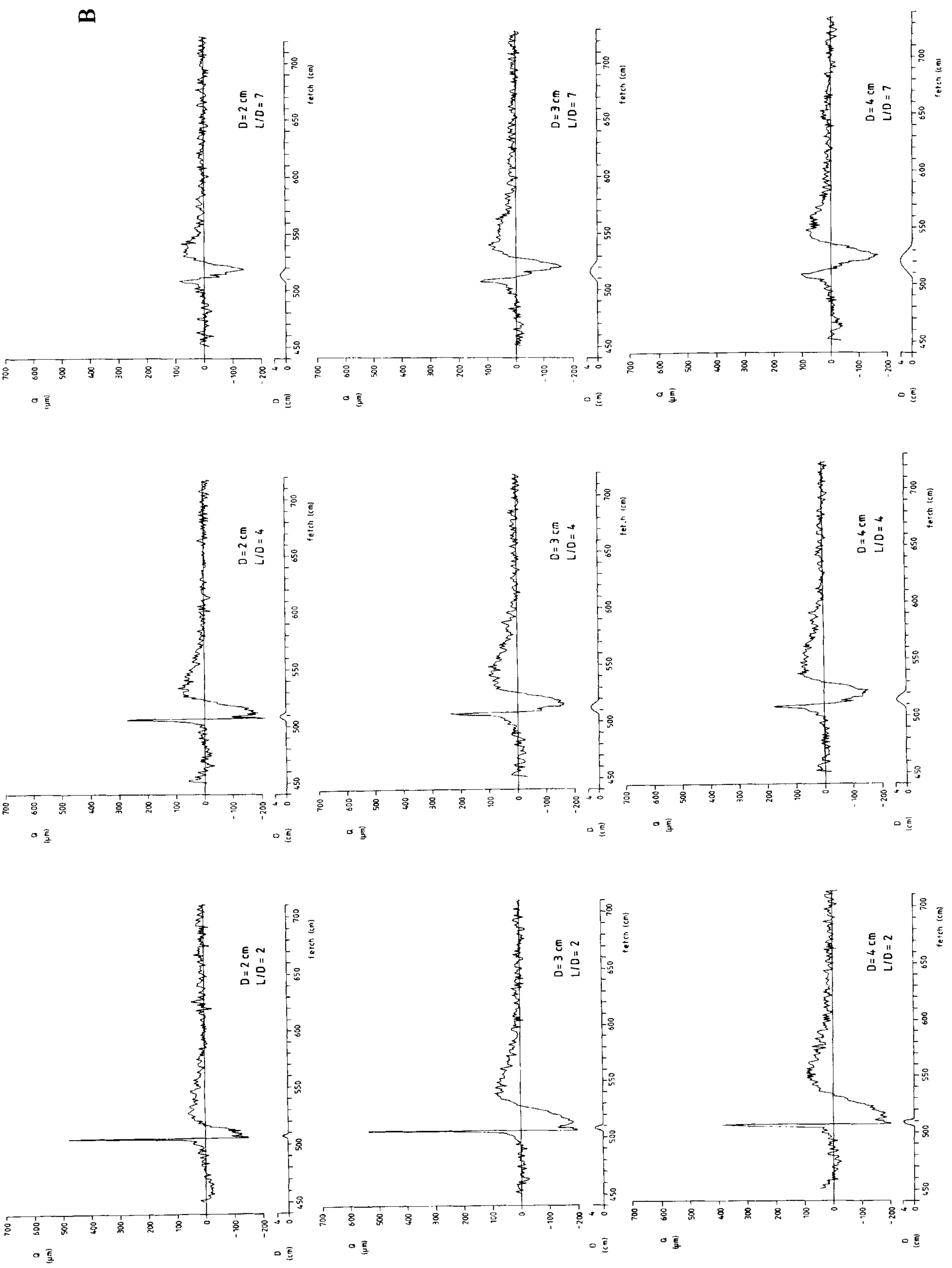
B
D = 2 cm
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a (μm)
D (cm)
fetch (cm)

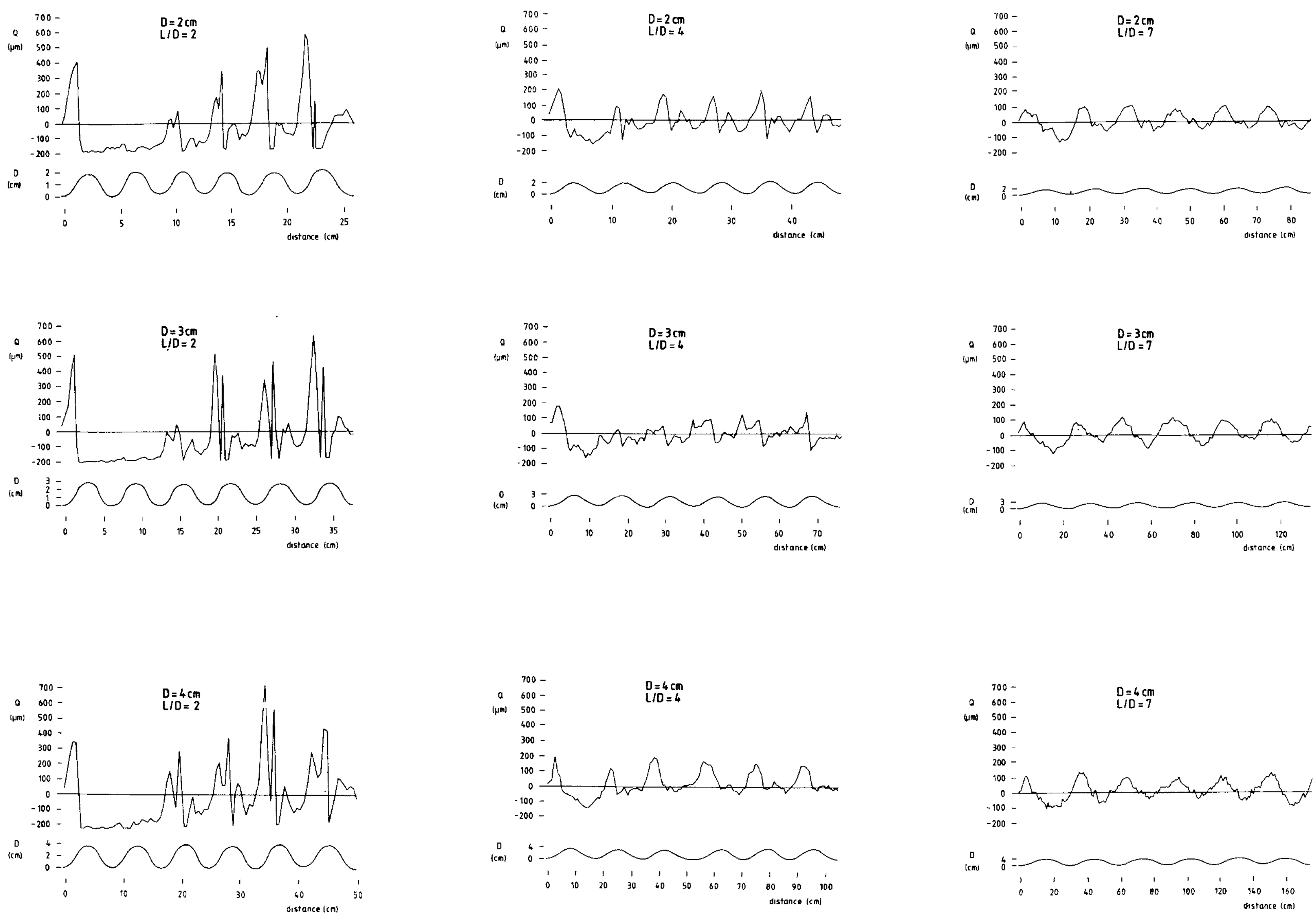

Figure 3. Six-hill deposition profiles for the nine combinations of D and L/D. The position of the hills is indicated below each curve. See text for aerodynamic conditions; airflow is from left to right. Q = dust depth difference between the curved hill surface and a flat reference surface

In order to measure the deposition upstream and downstream of the hilly surface, the test substratum was lengthened with zinc plates 50 cm long (upstream) and of a variable length (downstream).

Each experiment lasted 15 min. During the experiments, dust was added to the airstream in the return section of the wind tunnel. Dust discharge was $13{\cdot}3\,\mathrm{kg\,h^{-1}}$, corresponding to an air dust concentration, at 5 cm above the surface, of about $1{\cdot}5\,\mathrm{g\,m^{-3}}$ at the onset of the first hill (fetch 505 cm). After the experiment, the dust-covered surface was taken out of the wind tunnel, and the depth of the dust layer determined by means of the Optocator instrument. Because the measuring range of the 2301 gauge probe was restricted to only 0·8 cm, no continuous scans could be made of the global test surfaces since the height of the hills was always significantly beyond this value. Therefore, each surface was scanned in succeeding steps, and dust thickness was measured every 0·2–1·0 cm (varying from substratum to substratum), or at even shorter intervals when this appeared to be necessary.

After dust thicknesses had been determined, the substrata were cleaned and a new scan made along the same line to determine the exact shape of the topographic profile. This second scan was done with the 2008 gauge probe, and measurements were carried out every 0·1 cm.

In order to eliminate the effect of spontaneous sedimentation fall as a function of fetch, a further experiment was conducted under exactly the same conditions, but with a completely flat (uncurved) substratum. By subtracting the dust thicknesses of the flat surface from those of the curved (hill) surfaces, the effect of the hills on the deposition of dust could easily be determined.

RESULTS AND DISCUSSION

Figure 2 is a compilation of the dust profiles measured. The ordinate values represent the difference in dust depth between the curved (hill) substrata and the flat (reference) substratum. The effect of surface topography is very pronounced: all profiles show a considerable increase of deposition on the concave part of the windward hillslope, a sharp decrease about half-way up the windward slope, a deep minimum immediately before the top, a local increase behind the top, a second minimum on the leeslope, and again an increase of deposition when the windward slope of the next hill is reached. Downwind from the last hill, an important secondary maximum is observed, after which deposition evolves gradually to the 'normal' value. The general characteristics of the dust profile over a single, isolated hill remain, therefore, recognizable in the sedimentation profile over a range of hills. However, at $L/D = 2$, very little dust settles on hill no. 2 (the second hill in the row, calculating in the downwind direction). Hill no. 2 is located in the dust shadow created by hill no. 1.

To get a more detailed image of the sedimentation patterns near the hills, the central part of each six-hill profile was redrawn and enlarged, as shown in Figure 3. The figure shows, horizontally, the effect of L/D on the sedimentation profile, and vertically, the effect of hill height D. Both D and L/D are a measure of the degree of topographic 'flattening' of the test surface. The lower the value of D and the larger L/D, the smaller is the degree of incision.

Comparison of the sedimentation profile over a single, isolated hill with the sedimentation profile over a series of six identical hills

Comparing the sedimentation profiles over the six-hill substrata with the corresponding profiles over the one-hill substrata, the following observations can be made:

(1) The deposition pattern on the windward slope of hill no. 1 (the most upstream-located hill) is identical to the deposition pattern on the windward slope of an isolated hill. Dust deposition increases on the concave slope, reaches a maximum near the inflection line, drops considerably on the convex slope, and is very low close to the top. The numerical differences in the sedimentation maxima between homologous one-hill and six-hill profiles are mainly a result of the experimental procedure adopted (step-by-step sampling of the profiles, i.e. the absolute maximum may have been missed), and are of no real significance. On the leeside, the situation depends upon the degree of topographic flattening. At low L/D values (sharply incised substrata), much more dust is found on isolated hills than on the first hill of a hill range, whereas at high L/D values (weakly incised substrata) the pattern is reversed.

(2) On isolated hills, the sedimentation maximum on the windward slope is always single and located on the concave part of the slope. On multiple-hill substrata, two possibilities occur:

(a) *sharply incised substrata* ($L/D = 2$): the sedimentation maximum on the windward hillslope changes from a single into a double maximum. The first maximum is located on the concave part of the slope, whereas the second maximum occurs on the convex part. The local minimum between the maxima occurs almost exactly at the inflection line, where the slope changes from concave to convex. The maximum on the convex slope is dominant, except when the concave slope is very steep.
(b) *moderately incised* ($L/D = 4$) *and weakly incised* ($L/D = 7$) *substrata*: the windward slope maximum remains single and is located on the concave part of the slope. (The zone of increased dust deposition as a whole, however, may still extend over a part of the convex slope.)

(3) The local increase of deposition on the convex leeslope (downwind of the top) is expressed much more on multiple-hill substrata than on isolated hills. On multiple-hill substrata, dust deposition in this area can even exceed the reference value observed upstream of the first hill, especially when the substratum is deeply incised (L/D is small). This is never the case on isolated hills (see Goossens, 1988b, 1988c, 1989; Goossens and Offer, 1993). If, however, topographic incision becomes small ($L/D = 7$), the sedimentation maximum downwind of the top degrades into a rather local, much less important peak which only slightly affects the sedimentation profile.

(4) In a number of cases the minima in the sedimentation curve, both on the convex windward slopes and on the concave leeslopes, are much less emphatic on multiple-hill substrata than on isolated hills. This is particularly true for the moderately incised substrata ($L/D = 4$), especially when hills are large. For strongly incised ($L/D = 2$) and weakly incised ($L/D = 7$) substrata, the minima in the sedimentation curves do not differ substantially from each other.

It can be concluded that the dust deposition profile over a series of six identical hills may show substantial differences compared to the deposition profile over a single, isolated hill, dependent on the degree of topographic incision and the size of the hills.

Figure 4 shows why the sedimentation maximum on the windward slope of multiple-hill substrata changes from a single into a double maximum when substrata become strongly incised. The photograph shows the dust flow pattern above the $L/D = 2$ and $D = 4$ cm substratum. The white zones near the summits correspond to the areas where friction velocity exceeds accumulation threshold, and where all the settling dust is eroded away immediately. The darker the dust pattern in the picture, the higher the air dust concentration at that location. The darker the contour of a hill, the more accumulation occurs at that location. Figure 4 shows quite dramatically the large accumulation on the concave part of the windward slope of the first hill,

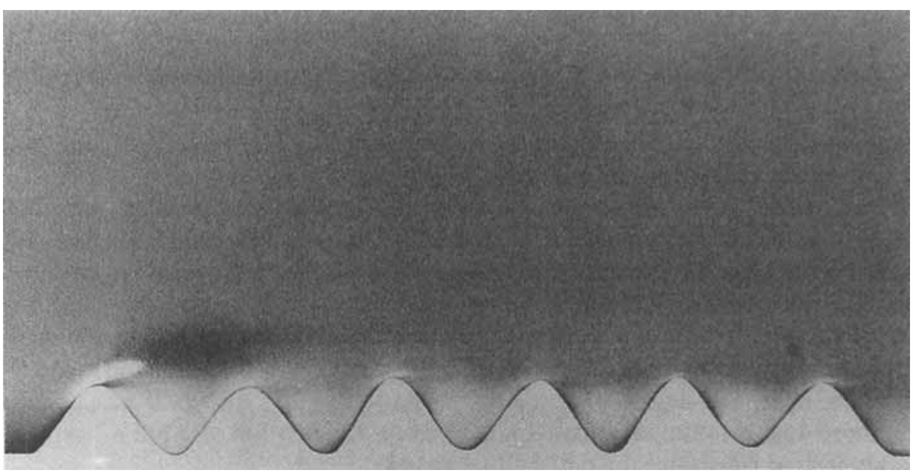

Figure 4. Transport of dust over a range of hills with $D = 4$ cm and $L/D = 2$. Aerodynamic conditions as in Figure 2 and 3; dust transport is from left to right

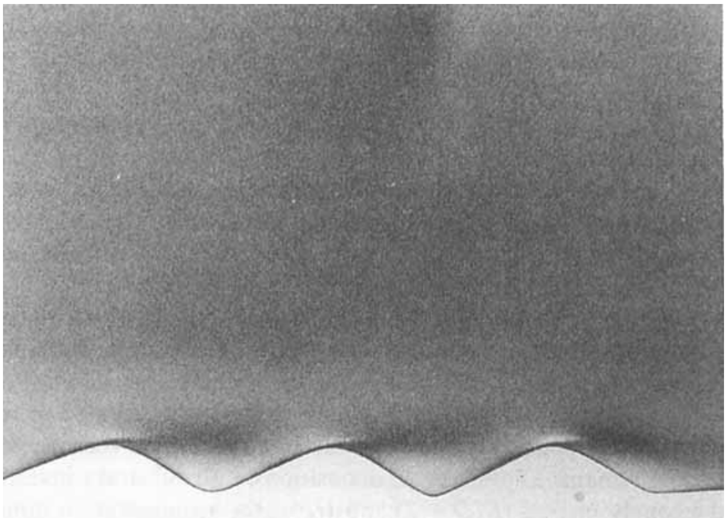

Figure 5. Transport of dust over a range of hills with $D = 4$ cm and $L/D = 4$. Aerodynamic conditions as in Figure 2 and 3; dust transport is from left to right

the zero accumulation on the convex windward slope (since accumulation threshold is exceeded at this location), and the very small (though not zero) accumulation more downwind. Also, the double accumulation maximum on the windward slope of the next hills, and the local maximum directly downwind from the top, are easily recognizable. Upwind from each top, wind speed is above the accumulation threshold, which results in zero accumulation on the surface (see also Figure 3).

In Figure 4, the hills succeed each other sufficiently closely to allow a hill to be located underneath the descending dust plume (of high concentration) that is created by the preceding hill. As a result, the convex windward slope of each hill, except hill no. 1, receives a considerable amount of dust, and a second sedimentation maximum is formed. The local minimum between both maxima occurs where the (lower) boundary of the descending dust plume reaches the surface (see Figure 4). When the hills are too far from each other (L/D is too large), the dust plume has become considerably 'diluted' when it reaches the convex windward slope, and no additional sedimentation maximum will be created (see Figure 5).

The descending dust plume also explains why the sedimentation minima are usually higher on multiple-hill substrata than on isolated hills. Due to their relatively large width, the plumes provide large parts of the topographic depressions, which do not profit from a significant longitudinal dust supply, with dust from above (see Figure 5). This explains the rather high sedimentation minima, which may even exceed sedimentation upstream of the first hill (Figure 3). Of course, if wind velocity increases beyond the accumulation threshold, the minima will be very low, even if these areas profit from a significant dust input from above.

Effect of L/D

Figure 3 shows, horizontally, the sedimentation profiles as a function of L/D, for the three hill heights tested. Several observations can be made:

(1) The more sharply a substratum is incised (i.e. the lower L/D), the more the sedimentation pattern over a range of hills is affected by the dust shadow created by the first hill. At weakly incised substrata ($L/D = 7$), no effects upon the deposition pattern on hills nos. 2, 3, 4, 5 and 6 are observed. At moderately incised substrata ($L/D = 4$) the sedimentation maximum on the windward slope of hill no. 2 is lower than the sedimentation maximum on the subsequent hills: a shadow effect becomes apparent. At strongly incised substrata ($L/D = 2$) the effect is very large: both the leeside of hill no. 1 and the whole of hill no. 2 are nearly

devoid of dust, and much less sediment than normal is deposited on hill no. 3. From hill no. 4, the effect has damped out.

(2) The sedimentation maximum on the windward hillslope is single on weakly and moderately incised substrata, but evolves into a double maximum as L/D decreases to a value of two. This phenomenon was discussed earlier.

(3) The local increase of deposition on the convex leeside becomes more important as L/D decreases. This phenomenon was also discussed earlier.

(4) The sedimentation maximum on the windward slopes become higher as L/D decreases. This is particularly true for the 2 cm and 4 cm hills, but also for the 3 cm hills. The sedimentation minima, on the contrary, are lower (although the differences between $L/D = 4$ and $L/D = 7$ are small). Thus, the smaller L/D, the larger the differences in dust depth become in the same profile.

(5) At weakly incised substrata ($L/D = 7$), the sedimentation minimum between two adjacent hills is located far upstream: dust deposition starts to increase on the convex part of the leeslope of the first hill instead of near the talweg. Consequently, the local increase of deposition downwind of the top, which is usually located on the convex lee, is also shifted upstream and is now situated nearly at (or even before) the top. All hills are now characterized by a significant dust deposition on their leeslope. However, deposition on the windward slope remains above leeside deposition at all substrata investigated. At moderately incised ($L/D = 4$) and strongly incised ($L/D = 2$) substrata, the sedimentation minimum is located close to the end of the first hill, which corresponds to the pattern observed at isolated hills. Why does dust deposition start to increase so early on substrata of high L/D? At such substrata, the dust plume created by a hill settles not only over the windward side of the subsequent hill, but also over a large part of the leeslope of the hill itself. The leeslope is, therefore, provided with dust from above, which is not the case when hills are located sufficiently close to each other.

It can be concluded that the degree of incision (characterized by the ratio L/D) of a substratum significantly affects the dust deposition pattern on that substratum.

Effect of D

Figure 3 shows, vertically, the dust profiles as a function of hill height D, for the three degrees of incision tested. There are no substantial differences, except for the local increase of deposition downwind of the top. The smaller the hills, the more important this local maximum becomes. This trend is strongly expressed at the weakly incised ($L/D = 7$) and moderately incised ($L/D = 4$) substrata. At strongly incised ($L/D = 2$) substrata, the local maximum downwind of the top is well developed at all three hill heights investigated.

Finally, reference must be made to a local sedimentation maximum that occurs in the talwegs of the $D = 3$ cm and $L/D = 4$ substratum. This maximum does not occur in any of the eight other profiles. It is thus a rather isolated phenomenon, the origin of which remains unclear.

Relevance to field conditions

It should be noted that the wind tunnel experiments discussed in this paper refer to *short-term* dust deposition. Figures 2 and 3 show the dust patterns that will be observed after the passage of a dust storm, i.e. a short-term event. After a sufficiently long time, depending on the meteorological characteristics of the test site, these initial patterns may show significant changes. In desert environments, rainfall is a very important parameter since heavy floods will wash large amounts of dust from the hillslopes. This dust accumulates in the wadis (Evenari *et al.*, 1982). These phenomena seriously alter the final accumulation pattern of the dust. However, it is true that if the hillslopes are able to trap significant amounts of sediment and if there is any dust to be accumulated on these slopes then the final accumulation pattern will show good agreement with the initial deposition pattern, provided that the trapping efficiency is similar for all slopes and the direction of the dust-bearing winds is sufficiently constant. Detailed studies of long-term dust accumulation in the Belgian loess belt have shown that the final accumulation patterns are remarkably similar to the short-term deposition patterns simulated in the wind tunnel (Goossens, 1988a). If, on the other hand, the trapping efficiency of the slopes is low to very low (such as in many arid and hyper-arid deserts), most of the settled dust is blown away by the wind very quickly, and no important long-term accumulation occurs. Field

experiments by Goossens (1995) suggest that, for the Negev desert in Israel, less than 20 per cent of the settled dust is retained from further erosion. The remaining 80 per cent is eroded by post-depositional wind and water erosion, and dust accumulation in the field remains small to very small.

CONCLUSIONS

The experiments indicate that the dust deposition profile over a range of identical hills may significantly differ from the dust deposition profile over single, isolated hills. They also show that both the height D of the hills and the degree of incision of the surface (characterized by the ratio L/D, where L is the spacing between the hills) have a significant effect upon the final deposition pattern. The main conclusions of the study can be summarized as follows:

1. On isolated hills, the sedimentation maximum on the windward hillslope is always single and located on the concave part of the slope. On a range of hills, the maximum is either single (and located on the concave part of the slope) or double (with a first peak on the concave and a second peak on the convex slope), dependent on the degree of incision of the surface. Strongly incised surfaces show a double maximum, whereas moderately and weakly incised surfaces show only one maximum.
2. The local increase of dust deposition on the convex leeslope of the hills is expressed much more on multiple-hill substrata than on isolated hills, especially when hills are small and the topographic incision high.
3. Dust deposition on the leeside of an isolated hill is markedly lower than dust deposition on the leeside of an identical hill standing in the front of a row of hills, except when the degree of topographic incision is high. In the latter case, the situation is reversed.
4. Multiple-hill substrata are characterized by the presence of a dust-shadow area, created by the most upstream-located hill. Dust deposition profiles may or may not be affected by this shadow, depending on the degree of incision of the surface. The more quickly the hills succeed each other, the further downwind the shadow effect penetrates into the deposition profile. Surfaces with an L/D value of 7 and more are no longer affected by the phenomenon, at least not at the wind speeds and hill sizes tested.
5. The more strongly a substratum is incised, the larger the differences in dust depth on the substratum become. The sedimentation maxima become higher (i.e. a thicker dust layer), whereas the minima are lower (a thinner dust layer) or remain constant.
6. The sedimentation minimum between two adjacent hills shifts upwind as the substratum becomes smoother. At low L/D values, the minimum is located near the talweg, whereas it occurs on the convex part of the leeslope of the upwind-located hill if L/D is large. Also, the position of the local maximum downwind from the first sedimentation minimum is shifted upwind.
7. The dust plume (of high concentration) that is created by a hill plays an important role in the deposition pattern on the succeeding (downwind) hill. Owing to the dust supplied from above by the descending plume, areas on the second hill that would otherwise be devoid of dust are now characterized by significant dust deposition. This is particularly true on the convex windward slopes of strongly incised substrata, where a second sedimentation maximum is formed. Also, the rather high sedimentation minima (compared to isolated hills) and the important deposition on the leeward slopes of weakly incised substrata are a result of the descending dust plume.

The dust deposition profile over a range of six identical hills is, therefore, fundamentally different from a succession of six individual profiles over isolated hills.

It should be recalled that in this study, all multiple-hill substrata were composed of six hills. All hills were symmetrical, the slopes were concave–convex, and the length axes of the hills were always perpendicular to the direction of wind (and dust supply). All hills of the same substratum were of identical size and shape, and hill spacing was constant along the test surface. For practical reasons, no L/D values larger than 7 were investigated. All experiments were also done at one wind condition only. Finally, only transverse dust profiles (perpendicular to the hills) were analysed. Longitudinal patterns were not investigated.

Further research, which should include different combinations of hill size, hill shape and hill spacing, is required to extend the results of this preliminary study. In addition, adequate field tests, in which dust

profiles are measured along ranges of hills during real-size dust storms, are necessary to validate the wind tunnel results. Special attention should be devoted to the occurrence, size and shape of the plumes of high air dust concentration, since these plumes have a large effect upon the final deposition pattern.

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